

# An Empirical Study for Measuring the Visual Guidance Using Eye Tracking

Weihua Dong,<sup>1\*</sup> Bing Liu,<sup>1</sup> Huiping Liu<sup>1</sup>

1. Research Center of Geospacial Cognition and Visual Analytics, Faculty of Geographical Science, Beijing Normal University, China. dongweihua@bnu.edu.cn, liubing\_731@163.com, hpliu@bnu.edu.cn

\* Corresponding author

**Abstract:** Visual guidance is key to our ability to quickly understand the world. To date, studies of variables that affect these mechanisms in cartography have focused mostly on 2D maps, but 3D visualization, which is now widely used, may have different rules for guidance. In this study, we used eye tracking to analyse the visual guidance of shape, colour and size in 3D visualization. Thirty-six subjects (24 female and 12 male) participated in the study. The results indicated that the visual guidance mechanisms for these visual variables in 3D visualization differ significantly from 2D maps. Colour and shape provide a high level of visual guidance, but the guidance provided by size, a variable that guides the deployment of attention in 2D maps, is much more limited in a 3D environment.

**Keywords:** 3D visualization, Visual guidance, Visual variables, Eye tracking

## 1 Introduction

Visual guidance is important to our perception of the world (Wolfe, 2012; Wolfe & Horowitz, 2004), and help us to perceive the world quickly. The development of new techniques for visualizing the natural world (such as 3D maps and virtual reality) has opened new and powerful ways to understand the world, which is important to know whether the computer-generated creations are properly understood by users. Visual guidance is key to the quick perception of 3D visualizations.

Studies of visual guidance have focused mostly on visual variables (colour, size and shape) in traditional 2D maps. Colour is the first aspect of visual cognition by which people get to know the world. Numbers (Grubert & Eimer, 2013), colour plates (D'Zmura, 1991) and other 2D symbols (Wolfe & Horowitz, 2004) have been used as carriers to demonstrate that colour provides important visual guidance in 2D object searches. Similar experiments have shown that subjects have more difficulty searching objects with specific shapes (Quinlan & Humphreys, 1987), and that the fixation time on objects of certain shapes in a scene is relatively short compared with those of certain colour or size (Williams, 1966), which means that shape provides weaker guidance than colour in 2D tasks. In a 3D environment, however, shape is more variable and has more identical characters (Pizlo, 2010), which means it could provide stronger guidance. Wolfe concluded that size clearly guides visual attention (2004), but this finding is based on one-dimensional size (length) (Treisman & Gormican, 1988). Due to the projection in 3D maps, the visual size of an object is not only related to its actual size but also to its location and some other projection factors. But few studies have compared the differences in 3D visualizations of colour, shape or size.

Eye-tracking has long been used in the study of geo-visualization. Studies have shown that observers' gaze patterns depend on the task (Ehinger, Hidalgo-Sotelo, Torralba, & Oliva, 2009; Hayhoe & Ballard, 2005), thus eye-tracking is a practical method for demonstrating the task process and not just the results (Brodersen et al, 2002). Eye-movement tracking is widely used in map design improvement (Brodersen et al., 2002; Dong, Liao, Xu, Liu, & Zhang, 2014; Ooms, De Maeyer, & Fack, 2010) and in comparisons of geo-visualization methods (Dong, Liao, Roth, & Wang, 2014; Popelka & Brychtova, 2013; Putto, Kettunen, Torniainen, Krause, & Tiina Sarjakoski, 2014). Eye-

tracking is also commonly applied to understand how people understand and comprehend the natural world (Hayhoe & Ballard, 2005) and the visualization of it (Gienko & Levin, 2005; Kiefer, Giannopoulos, & Raubal, 2014).

In this study, we use eye-tracking to evaluate the difference in visual guidance for three common 3D visual variables, colour, shape and size.

## 2 Methods and Materials

### 2.1 Participants

36 undergraduate/graduate students from Beijing Normal University took part in this experiment. There were 12 male and 24 female students, with an average age of 22 years old ( $SD=4.06$ ). None of them reported to have the condition of colour anomalia. All of the subjects had normal or corrected-normal vision.

The participants were randomly divided into 6 groups.

### 2.2 Apparatus

Tobii Studio (<http://www.tobii.com/>) eye-tracking technology was used in the experiment. The software, Tobii Studio 3.2, was installed on a Lenovo PC. A Tobii T120 Eye Tracker, with a sampling rate of 120 Hz, mounted on a 17-inch TFT display, which at the time of the study had been used for two years, with a screen resolution of 1024\*768, was used to record the participants' eye movements.

### 2.3 Materials and procedures

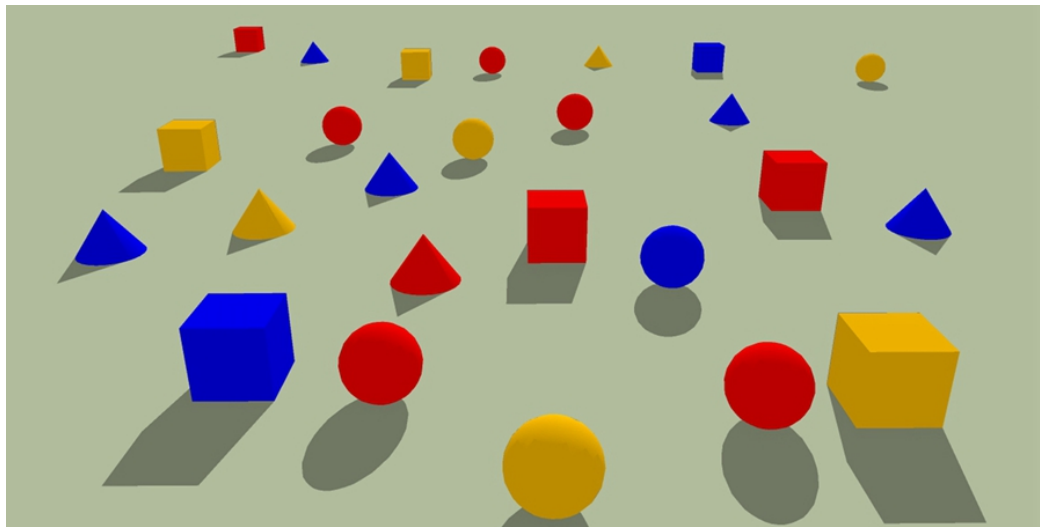
We used Google SketchUp to edit the stimuli ( $FOV=35^\circ$ , height of viewpoint  $h=50$  m). The original material was true-3D, and was screenshot, so the stimuli were pseudo-3D.

The first two testing stimuli included cubes, spheres and cones of the same size (the side length of the cubes was equal to the diameter of the spheres and cones) but of different colours, which could be red, yellow or blue (**Fig. 1**). Subjects were asked to find and click objects of a certain shape or colour. The third stimulus was yellow cubes, three of which were expanded to 120% of the original size. Subjects needed to find and click the bigger cubes without knowing exactly how many they should find.

Each part of the experiment began with a practice stimulus in which the subjects first listened to the experimenter explain the task (**Table 1**) while the practice stimulus was shown on the screen. Once the subject confirmed that he/she understood the task, he/she could click the mouse to see the instructions and complete the tasks with no interference from the experimenter.

**Table 1** Experiment tasks

	Attribute	Task
<b>Exp1</b>	Shape	Find and click on all the spheres(G1-G2)/ cones(G3-G4)/ cubes(G5-G6).
<b>Exp2</b>	Colour	Find and click on all the red(G1-G2)/ blue(G3-G4)/ yellow (G5-G6) objects.
<b>Exp3</b>	Size	Find and click on all the cubes (1 or many) that are bigger than others.



**Fig. 1** Stimulus of G1-G2 in Exp1 concerning shape visual guidance. Participants were asked to find all the spheres. Stimulus of Exp1.2 was similar.

### 3 Analysis and Results

#### 3.1 Analysis Framework

In the first part, we used gaze path and five indices to analyse the visual guidance of colour, shape and size. Gaze path can show the viewing order (Cöltekin, Fabrikant, & Lacayo, 2010). Although it provides valuable information, gaze path is rarely used in eye-tracking analysis, because its complexity makes extraction of useful information too difficult (Cöltekin, Heil, Garlandini, & Fabrikant, 2009; Dong, Liao, Roth, et al., 2014; Irina Fabrikant, Rebich-Hespanha, Andrienko, Andrienko, & Montello, 2008). However, in this study, the task is simple and requires just a short time, so the gaze path is also simple. In addition, we chose just one example of a gaze path to illustrate the process.

In our experiment, each target was identified as an AOI, and all the AOIs within one single image were formed into an AOI group. Five indices used to analyse the visual guidance of a visual variable are: *finish time*, time needed to complete the task; *time to first fixation*, time from start of task until the subject fixates on the AOI group for the first time; *right-click*, finish time/correctly judged number; *accuracy*, correctly judged number/click number; and *visit ratio*, visit duration on AOI group/total visit duration.

A T-test or M-W U test (depending on whether the statistics fit a normal distribution) was used to test the significance of the difference.

#### 3.2 Eye-tracking-based performance

**Fig. 2** shows gaze plot of visual guidance tasks for one subject (G1, Rec 12; a 22-year-old male junior student who frequently uses 3D) as an example of the qualitative analysis. Each circle represents a fixation, the diameter of the circle represents fixation duration and the number within the circle represents the fixation sequence.

In **Fig. 2(a)**, the subject was asked to find all eight spheres. The first eight fixations are almost all on blue objects, with the exception of Fixation No. 5. After the seventh fixation on a blue cone, the subject notices the next blue cone and skips the closer yellow sphere (target). Shape shows weaker attractiveness than does colour. After this period, however, when the subject became used to the process and repeated the task, he could identify all the spheres quickly and correctly.

Subjects needed to find all nine red objects in **Fig. 2(b)**. There are fewer fixations even though there are more target subjects to find. And almost all the fixations are on targets, which mean the visual guidance of colour is stronger.

As for size, there were 3 bigger objects to find, but fixations were distributed on all the cubes (**Fig. 2(c)**). This distribution might occur because subjects did need to look at all the objects and compare to find the “bigger” ones. However, the scan-path shows a horizontal trend, which means subjects couldn’t “feel,” or perceive by split vision, the difference in size. The visual guidance of size is thus relatively weak. The finish time for colour (7.924 s) is shorter than for shape (10.318 s), and the FT (finish time) for size (11.298 s) is the longest. The difference in FT between colour and shape/size is significant ( $t_{c-sp}=3.390$ ,  $p_{c-sp}=0.001$ ;  $t_{c-sz}=-3.401$ ,  $p_{c-sz}=0.001$ ), while the difference between shape and size is not ( $t_{sp-sz}=-0.856$ ,  $p_{sp-sz}=0.395$ ).

The TtFF (time to first fixation) for colour is the shortest; subjects needed just 1.281 s on average to fixate on the target, while they needed 1.635 s and 1.744 s on average to first fixate on the target object with a certain shape or size. However, these differences are all insignificant, with  $Z_{c-sz}=-0.501$ ,  $p_{c-sz}=0.616$ ;  $Z_{c-sp}=-0.192$ ,  $p_{c-sp}=0.192$ ;  $Z_{sp-sz}=-0.746$ ,  $p_{sp-sz}=0.456$ .

RC (right-click) shows the same trend as FT and TtFF. RC for colour is 0.952 s, significantly shorter than that for shape ( $RC_{sp}=1.554$  s,  $t_{c-sp}=5.143$ ,  $p_{c-sp}=0.000$ ) or size ( $RC_{sz}=7.280$  s,  $t_{c-sz}=-10.440$ ,  $p_{c-sz}=0.000$ ). RC for shape is also significantly shorter than that for size ( $t_{sp-sz}=-9.304$ ,  $p_{sp-sz}=0.000$ ).

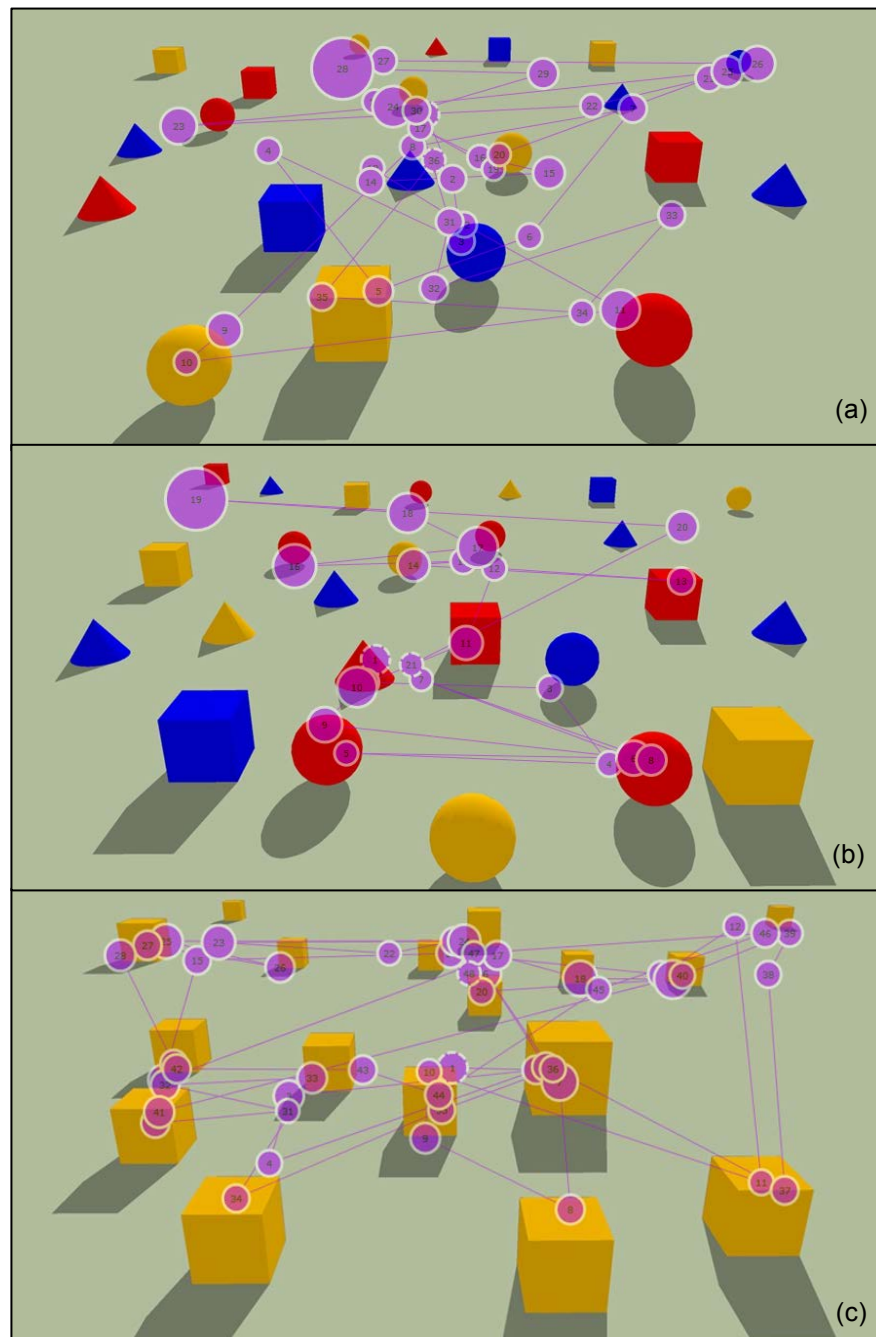
Numerically, the VR (visit ratio) displays a different tendency from the indices above. The VR for colour is the largest and that for size is smallest ( $VR_c=0.276$ ,  $VR_{sp}=0.192$ ,  $VR_{sz}=0.116$ ). In addition, the differences between colour and shape, or colour and size, are both significant ( $t_{c-sp}=-2.182$ ,  $p_{c-sp}=0.033$ ;  $t_{c-sz}=5.001$ ,  $p_{c-sz}=0.000$ ), and that between shape and size is also significant ( $t_{sp-sz}=3.050$ ,  $p_{sp-sz}=0.004$ ). However, a larger VR means that when completing this task, subjects are doing more useful work. So in fact, the VR shows the same tendency as the other indices.

Accuracy for colour is the highest (1.000); all subjects completed the task correctly. Accuracy for shape is lower, at 0.956. One subject clicked so fast that he did not fully understand the task instructions and three did not find all the targets. Accuracy for size is 0.593, which is the lowest. Only 12 subjects found all the targets without regarding other objects as targets.

In this part, we analysed gaze plot and five quantitative indices to illustrate visual guidance of shape, colour and size in 3D visualization. All the results indicate that with 3D displays, colour and shape have clearer attention attractiveness while visual guidance for size is weaker.

**Table 2** Statistics of Visual Guidance Tasks

	Efficiency		Effectiveness		
	Finish time (s)	Time to first fixation (s)	Right-click time (s)	Accuracy	Visit ratio
Shape	10.318	1.635	1.554	0.956	0.192
Color	7.924	1.281	0.952	1.000	0.276
Size	11.298	1.744	7.280	0.593	0.116



**Fig. 2** Gaze plots of G1, Rec 12 (Fig4(a)), Exp1.2(Fig5(b)) and Exp1.3(Fig5(c))

**Table 3** Result of significance testing in visual guidance task

Finish time (t(p))	Shape	Color	Time to first fixation (Z(p))	Shape	Color
Color	3.390(0.001)		Color	-0.192(0.192)	
Size	-0.856(0.395)	-3.401(0.001)	Size	-0.746(0.456)	-0.501(0.616)
Right-click time (t(p))	Shape	Color	Visit ratio (t(p))	Shape	Color
Color	5.143(0.000)		Color	-2.182(0.033)	
Size	-9.304(0.000)	-10.440(0.000)	Size	3.050(0.004)	5.001(0.000)

## 4 Conclusion

### Differences in visual guidance between colour, size and shape

Guidance for visual variables is not the same as it is in 2D visualization. Wolfe summarized the research on the guidance of visual variables in 2D displays and found that colour and size are most capable of visual guidance, while for shape, this is not clear (Wolfe & Horowitz, 2004).

In our 3D-object experiment, colour provides the same strong guidance as it does with 2D objects (D'Zmura, 1991; Grubert & Eimer, 2013). This is because colour is not a scene-based visual variable. Although its appearance may be influenced by illumination, the colours we used here are quite distinct from each other, so the subjects can still notice the targets.

However, in 3D visualization, visual guidance provided by shape is stronger than that provided by size. This may be because in 3D displays, unlike a 2D surface and length, the "1D size," the same object's image on a retina is smaller when it is far away. Subjects who are aware of this effect will automatically supplement the size (Gori, Giuliana, Sandini, & Burr, 2012; Granrud, 2004, 2012), and this requires more time. Also, in a symbolic representation, as distinct from the real world, there are not as many objects in the background, resulting in a lack of distance hints (Wagner 2012), which are important to the perception of size (Brenner & van Damme, 1999; Hatfield, 2014; Kenyon, Phenany, Sandin, & Defanti, 2008). When people could not perceive the correct size, it was unable to successfully guide visual attention.

As for shape, in going from a 2D to a 3D visualization, shape takes on an extra dimension, which means more characters are needed to identify any particular shape. The complexity of visual guidance for shape may also be related to the type of shape used. For example, shapes using letters provided strong visual guidance (Quinlan & Humphreys, 1987) in 2D visualization, but, according to L.Chen (1982), the shape sensitivity of lines is influenced by its conjunction with other shapes.

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